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**Method of assembling and monitoring an acoustic panel  
comprising a double resonator with a honeycomb core**

**Description**

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**Technical field of the invention**

The invention relates to acoustic panels comprising a  
double resonator with a honeycomb core and, more  
10 specifically, to a method of assembling and monitoring  
such panels.

**Prior art and problems to be solved**

15 Acoustic panels comprising a double resonator with a  
honeycomb core are well-known sandwich structures for  
absorbing noise, in particular on aircraft power  
plants. These panels usually include the following  
successive layers in the direction of the thickness: a  
20 first "acoustic" skin which is multiperforated, that is  
to say including a plurality of holes, a first,  
"primary" honeycomb layer, a likewise multiperforated  
septum, a second, "secondary" honeycomb layer, and a  
second skin referred to as "solid skin" because it does  
25 not include any holes. The honeycombs consist of a  
plurality of generally hexagonal cells, these cells  
being separated by thin partitions themselves including  
drainage slots for discharging by gravity the water  
which might have entered the acoustic panel during its  
30 use. The holes in the acoustic skin and in the septum  
are regularly distributed and are each characterized by  
their degree of perforation, that is to say by the  
ratio of the area of the holes to the total area of the  
layer in question. The acoustic skin and the solid skin  
35 are usually made of composite material having an  
organic matrix and consist of a variable number of  
reinforcing fabric layers placed one above the other  
and embedded in a cured resin. The honeycomb layers are

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usually made of aluminum strip.

5 The acoustic properties of the panel, that is to say its degree of noise absorption as a function of the frequency and of the sound level of the noise, depend on the dimensioning of the components of the panel and, in particular, on the degrees of perforation of the solid skin and of the septum.

10 Each layer is manufactured separately and methods of doing so are well known. The acoustic skin is usually pierced with a drill because the size of the holes allows this to be done without difficulty. The septum may be pierced with a drill, but it is preferred for  
15 piercing to be carried out with a laser beam because of the small size of the holes and the large number thereof.

20 The acoustic panel is then assembled by placing the various preglued layers on a mold having the required shape and exposing the assembly to a heat cycle in an autoclave with the aim of clamping the layers against one another and of curing the adhesives. It should be noted that the solid skin may be produced and glued on  
25 the panel in a single operation.

The critical phase of the assembly method is the assembly of the septum with the two honeycomb layers by gluing. This is because, during the assembly, a  
30 fraction of the holes in the septum is normally blocked by the adhesive and this is taken into account in order to define the degree of perforation of the bare septum, that is to say before its assembly. This fraction easily reaches 50%. Too low or too high a fraction  
35 significantly changes the acoustic properties of the panel and makes it unsuitable for the use which was intended. This fraction is minimal when the cells of each of the honeycomb layers are in phase, that is to

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say correctly face one another, because the adhesives used for assembling each of the honeycombs with the septum substantially block the same holes in the septum. This fraction becomes maximal when the cells of each of the honeycombs are in phase opposition, that is to say have a maximum offset. The geometry of the honeycombs is unfortunately imprecise and the phenomenon which has just been described can consequently only be controlled with difficulty.

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This fraction also depends on the quantity of adhesive used, but the actual gluing operation for its part can be effectively controlled.

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The holes in the septum are usually very small, i.e. have a diameter of around 0.3 mm with about 50 holes per centimeter squared. Such a septum is pierced before assembly using a drill but preferably with a laser beam. The number and smallness of the holes make the piercing operation difficult. Thus, even though the piercing method is fairly well controlled, defects may arise.

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It is known to measure the standard resistance of the bare septum, that is to say before any assembly, with a pressure loss measuring system referred to more simply as a "raylometer". However, this method has some disadvantages:

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- the raylometer is an unstable pneumatic apparatus and it requires frequent recalibrations;
- monitoring the bare septum is a lengthy process because the raylometer has to be successively applied at various locations on the panel and it is necessary to wait until the measurement has stabilized before taking it into account;
- monitoring septums of large size requires special, and therefore expensive, raylometers because they must be able to reach the center of the septums.

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The inventors are not aware of any satisfactory means for measuring the characteristics of a finished panel during production. In fact, a measurement performed  
5 with the aforementioned raylometer is marred by very considerable errors caused by lateral leaks through the drainage slots in the partitions and also by the inevitable misalignment of the two honeycomb layers.

10 There is also known another measuring instrument referred to as a "Kundt's tube" allowing direct measurement of acoustic impedance. Unfortunately, the measurements performed with a Kundt's tube on the panel described above are likewise marred by very  
15 considerable errors arising from the cells of the honeycomb overlapping the edge of the Kundt's tube when it is applied against the panel.

A first problem to be solved is to propose a method of  
20 assembling and monitoring acoustic panels which makes it possible to guarantee the intended acoustic characteristics.

A second problem to be solved is to detect as early as  
25 possible any defects likely to adversely affect the characteristics of the panel, in order to be able to interrupt the assembly process and, consequently, not to carry out unnecessary assembly operations.

30 A third problem is to propose a reliable assembly and monitoring method which is relatively inexpensive.

#### Summary of the invention

35 The invention proposes a method of assembling and monitoring an acoustic honeycomb panel comprising a double resonator, the panel consisting of a plurality of layers to be assembled in the direction of the

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thickness of the panel, namely: an acoustic skin, a primary honeycomb, a septum pierced with a plurality of holes, a secondary honeycomb and a solid skin, the method including preliminary operations of gluing the various layers to be assembled.

Such a panel is noteworthy in that:

- in a first step, the two honeycombs are assembled with the septum by gluing in order to constitute a subassembly, this assembly unfortunately having the effect of inevitably obstructing a fraction of the holes in the septum;
- subsequent to the assembly of the two honeycombs with the septum and prior to the assembly of at least one of the two skins, at least one of the honeycombs thus being uncovered, the degree of perforation of the septum is monitored by scanning the subassembly with a digital camera including an associated illumination system, the camera being arranged on the same side as an uncovered honeycomb, the camera thus taking shots of the septum at the bottom of the cells of the uncovered honeycomb, this illumination system illuminating the region of the septum observed by the camera, the successive images thus obtained being transmitted to a computer, the computer analyzing the images and establishing the degree of perforation  $T$  of the septum by applying the formula  $T = N1/N$ , in which  $N1$  is the number of pixels corresponding to the free holes and  $N$  is the number of pixels of the image.

It will be understood that the invention makes it possible to monitor the proper execution of the critical phase of the assembly method, namely the assembly of the septum with the two honeycombs. Thus, because the other assembly operations are able to be effectively controlled, implementing the invention makes it possible to guarantee that acoustic panels are

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obtained with performance levels as close as possible to those which they were designed to have, providing a solution to the first problem.

5 It will also be understood that the invention makes it possible to monitor as early as possible the proper execution of the critical phase of the assembly method since this monitoring can be carried out immediately after this critical phase, thereby solving the second  
10 problem. When monitoring shows the septum to be defective, the unnecessary operations of assembling the skins may therefore be avoided.

It will also be understood that the assembly and  
15 monitoring method is relatively inexpensive because it may be interrupted when the critical phase has not proceeded properly and because the monitoring means are themselves relatively inexpensive.

20 It will finally be understood that the present invention has required the selection and design of specific monitoring means, since the raylometer and the Kundt's tube do not provide sufficient precision, unlike the image acquisition and analysis method  
25 proposed.

Advantageously, and prior to the assembly of the septum with at least one of the honeycombs, the degree of perforation  $T$  of the bare septum is monitored by  
30 scanning the septum with a digital camera including an associated illumination system, this illumination system illuminating the region of the septum observed by the camera, the successive images thus obtained being transmitted to a computer, this computer  
35 analyzing the images and establishing the degree of perforation  $T$  of the septum by applying the formula  $T = N1/N$ , in which  $N1$  is the number of pixels corresponding to the free holes and  $N$  is the number of

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pixels of the image.

This inexpensive monitoring operation makes it possible not to initiate assembly of acoustic panels starting  
5 from defective septums.

The invention will be better understood and the advantages provided thereby will become more clearly apparent in the light of a detailed exemplary  
10 embodiment of the method and in the light of the appended figures.

#### **Description of the figures**

15 Figure 1 illustrates an acoustic panel to which the invention can be applied.

Figure 2 illustrates a bare septum.

20 Figure 3 illustrates an assembled septum.

Figure 4 illustrates the monitoring of a bare septum.

Figure 5 illustrates the monitoring of a an assembled  
25 septum.

#### **Description of a detailed exemplary embodiment**

Reference will be made first of all to figure 1. The  
30 acoustic panel 10 is a laminated structure consisting of the assembly of various layers in the direction of the thickness, namely successively: an acoustic skin 20, a "primary" honeycomb 30, a septum 40, a "secondary" honeycomb 50, and finally a solid skin 60.

35 The acoustic skin 20 is usually made of composite material with an organic matrix consisting of five to fifteen layers of reinforcing fabric (not shown), these

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fabrics being embedded in a polymerization-cured resin, these fabrics usually consisting of glass, carbon or Kevlar fibers. The acoustic skin 20 is pierced with holes 22 in a regular mesh pattern, their diameter  
5 being around 1 mm to 3 mm, the degree of perforation, that is to say the ratio of the total area of the holes 22 to the area of the acoustic skin 20, being around 15 to 25%.

10 The primary honeycomb 30 consists of adjacent cells 32 oriented in the direction of the thickness of the honeycomb 30, these cells 32 being separated by thin partitions 34, these partitions 34 including drainage  
15 slots 36 adjacent to the septum 40, these drainage slots 36 allowing the water that might possibly have entered the panel 10 through the holes 22 in the acoustic skin 20 to flow and be discharged. The cells 32 are most often hexagonal with an inscribed diameter,  
20 or width, usually between 3 mm and 10 mm, i.e. 1/8 to 3/8 inch. The partitions 34 may be made of aluminum strip.

The septum 40 is usually made of composite material with an organic matrix consisting of one to five folds  
25 of reinforcing fabric (not shown), these fabrics being embedded in a polymerization-cured resin, these fabrics usually consisting of glass, carbon or Kevlar fibers. The septum 40 is also pierced with holes 42 in a regular mesh pattern.

30 The secondary honeycomb 50 is similar to the primary honeycomb 30. However, its thickness or the width of its cells may be different. The reference numbers 52, 54 and 56 will be used respectively for its cells, its  
35 partitions and its drainage slots which are adjacent to the solid skin 60.

The solid skin 60 is similar to the acoustic skin 20,



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the solid skin 60 not being perforated, however, it being possible for the number and composition of the fabric folds and also the composition of the resin to be different.

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The reference number 70 will be used for the adhesive allowing the various layers of the panel 10 to be joined together.

- 10 Reference will now be made to figure 2. In this example corresponding to the most general form, the holes 42 in the septum are arranged along straight or slightly curved parallel lines 75, the distance between two successive lines being denoted by  $e$ , the pitch between  
15 two holes 42 on each line 75 being denoted by  $p$ . The degree of perforation  $T$  is then given by the formula:  
$$T = s/e \times p.$$

- The holes are pierced using a laser, the septum being  
20 arranged on a table having the same shape as it, the piercing apparatus being arranged at the end of a robot arm and passing over the septum by following the piercing lines 75.

- 25 Reference will now be made to figure 3. In this figure, the septum 40 is seen through the cells of one of the honeycombs 30, 50, for example through the cells of the secondary honeycomb 50. The primary honeycomb 30 is consequently not visible and its partitions 34 are  
30 represented in a broken line. The adhesive 70 is against the partitions 54 and extends slightly over the septum as far as a gluing limit 77, this gluing limit 77 consequently forming an approximately circular closed line. The holes 42 in the septum 40 appear  
35 inside the gluing limit 77, certain holes 42a being obstructed by the adhesive holding the primary honeycomb 30 on the septum 40, these blocked holes 42a being in the vicinity of the partitions 34 of the

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primary honeycomb 30. The reference number 42b will be used for the free holes.

Reference will again be made to figure 1.

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Moreover, the various layers 20, 30, 40, 50 and 60 are obtained, this involving holes 22 being pierced in the acoustic skin 20 and also holes 42 being pierced in the septum 40 and the pregluing of the layers. In a specific embodiment without a bearing on the present invention, the solid skin 60 may be produced and glued on the secondary honeycomb in a single operation and therefore with a single heat cycle.

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15 Reference will now be made simultaneously to figures 2 and 4.

Assembly of the panel is advantageously, but not mandatorily, preceded by monitoring the degree of perforation of the septum 40. This monitoring may be exhaustive but it will preferably be carried out by sampling to reduce the cost thereof. The monitoring may be carried out in the following way:

20 scan the bare septum 40 with a digital camera 84 comprising a lens 86 and an associated illumination system 88, 96, this illumination system 88, 96 clearly illuminating the region of the septum observed by the camera 84, the septum 40 being in practice arranged on a support 82, the successive images 92 thus obtained  
25 being transmitted to a computer 94, the computer establishing the degree of perforation T by applying the formula  $T = N1/N$ , in which N1 is the number of pixels 100 corresponding to the holes 42 and N is the number of pixels of the image 92. The resolution of the  
30 camera and the enlargement ratio of the image 92 are selected so that each hole 42 covers at least 30 pixels on the image. In a preferred embodiment, this resolution is selected so that each hole 42 covers from  
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75 to 100 pixels on the image, the precision of the measurement consequently being improved by reducing the influence of the pixels overlapping the edges of the holes.

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In the case where an episcopic illumination system 88 is used, the pixels 100 corresponding to the holes 42 are those whose light level is below a pre-established threshold level. In the case where a diasopic illumination system 90 is used, the pixels 100 corresponding to the holes 42 are those whose light level is above a pre-established threshold level. This threshold level is established by experimentation in order to give the most accurate measurement, that is to say so that statistically half the pixels overlapping the edge of the hole has a level below this threshold and so that the other half has a level above this threshold.

20 In the light of these results, the operator will reject the defective septums 40, that is to say those in which the degree of perforations is outside tolerance limits, and will possibly make adjustments to the setting of the machine which has carried out the piercing of the septum 40.

Reference will again be made to figure 1.

The assembly includes preliminary operations of pregluing various layers 20, 30, 40, 50 and 60 to be assembled, this pregluing being carried out preferably, but not mandatorily, in the following way:

- the acoustic skin 20 is preglued on its side which will be in contact with the primary honeycomb 30;
- 35 • the primary honeycomb 30 is preglued at the ends of the partitions 34 which will be in contact with the septum 40;
- the septum 40 is not exposed to any pregluing

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which could block the holes 42 thereof, because these holes are too small;

- the secondary honeycomb 50 is also preglued at the ends of the partitions 54 which will be in contact with the septum 40;
- the solid skin 60 is preglued on the side which will be in contact with the secondary honeycomb 50.

After their pregluing, the two honeycomb layers 30, 50, and possibly one of the two skins 20, 60, are then assembled using well known methods, the subassembly thus obtained being referenced 12. The surface of at least one honeycomb 30, 50 remains uncovered and makes it possible to see the septum 40 at the bottom of the cells.

Reference will now be made to figure 5. The subassembly 12 is monitored, exhaustively or by scanning, in the following way:

scan the subassembly 12 with a digital camera 84 including a lens 86 and an associated illumination system 88, 96, the camera 84 thus taking shots of the septum 40 at the bottom of the cells of the honeycomb 30, 50 between the septum 40 and the lens 86, this illumination system 88, 96 clearly illuminating the region of the septum observed by the camera 84 at the bottom of the cells of the honeycomb 30, 50, the subassembly 12 being in practice arranged on a support 82, the successive images 92 thus obtained being transmitted to a computer 94, the computer establishing the degree of perforation  $T$  by applying the formula  $T = N1/N$ , in which  $N1$  is the number of pixels (not shown) corresponding to the free holes 42b and  $N$  is the number of pixels of the image 92. The resolution of the camera and the enlargement ratio are selected so that each hole 42 covers at least 30 pixels on the image 92. In a preferred embodiment, this resolution is selected so

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that each hole 42 covers from 80 to 100 pixels on the image, the precision of the measurement consequently being improved by reducing the influence of the pixels overlapping the edges of the holes.

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In the case where an episcopic illumination system 88 is used, the pixels corresponding to the holes 42 are those in which the light level is below a pre-established threshold level, the adhesive 70 happens to appear on the image with a light level which is also below this threshold. In this case, the computer 94 delimits inside each cell the area 76 of the septum 40 not covered by the adhesive 70, the computer 94 then searching the pixels corresponding to the free holes 42b solely within the areas 76 thus delimited. This delimitation employs a well-known image analysis function allowing definition of an approximately circular closed line 77 having a size above a given minimum, this closed line 77 then being a boundary between a first region in which the light level is below a predefined threshold and a second region in which the light level is above this same level, this closed line 77 corresponding to the limit of the propagation of the adhesive 70 over the septum 40.

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In the case where neither of the two skins 20, 60 has yet been assembled, it is possible to use a diascope illumination system 90, the monitoring method then being identical to the above-described method of monitoring the bare septum.

The diascope monitoring procedure allows simpler image recognition because the free holes 42b appear very luminous and with an excellent contrast against a dark background. By contrast, it is more difficult to employ with large panels because the diascope illumination system 90 which is situated behind the panel with respect to the camera 84 has to follow the movements of

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this camera 84.

In the case where an episcopic illumination system 88 is used, the pixels 100 corresponding to the holes 42 are those in which the light level is below a pre-established threshold level. In the case where a diasopic illumination system 90 is used, the pixels 100 corresponding to the holes 42 are those in which the light level is above a pre-established threshold level. This threshold level is established by experimentation to give the most accurate measurement, that is to say so that statistically half the pixels overlapping the edge of the hole has a level below this threshold and so that the other half has a level above this threshold.

The resolution of the camera and the enlargement ratio of the image 92 are also selected so that each hole 42 covers at least 30 pixels on the image. In a preferred embodiment, this resolution is selected so that each hole 42 covers from 75 to 100 pixels on the image, the precision of the measurement consequently being improved by reducing the influence of the pixels overlapping the edges of the holes. The enlargement ratio of the camera 84 must not be too high, however, in order that this camera 84 has a sufficient field for each image 92 to completely cover at least one cell. In practice, this enlargement ratio is around 3 to 6.

Also in practice, the degree of perforation of the assembled septum must be equal to a mean value plus or minus 12%. In the event that the degree of perforation after assembly departs from these limits, the assembled septum 40 consequently being defective, the process of assembling the panel 10 is interrupted.

In a specific embodiment of the invention, the solid skin 60 is produced and glued on the secondary

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honeycomb 50. This arrangement has the advantage of requiring the solid skin 60 to be subjected to a single heat cycle ensuring simultaneous curing of the resin of the matrix and the adhesive.

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It will be understood that the present invention may be implemented with various sequences for assembling the acoustic panel, the important thing being that:

1. the septum is monitored subsequent to its assembly  
10 with the two honeycombs which are adjacent to it,
2. the septum to be monitored is visible from the  
outside through the cells of at least one  
honeycomb. In the case where the illumination  
system is episcopic, it is sufficient for the  
15 septum to be visible through one of the honeycombs  
and it is therefore possible for the monitoring to  
be performed after one of the skins has been  
assembled. In the case where the illumination  
system is diasopic, the septum must be visible  
20 through the cells of each of the honeycombs and it  
is thus necessary for the septum to be monitored  
before any assembly of the skins.

Also known are "triple resonator" acoustic panels  
25 including successively in the direction of the  
thickness: an acoustic skin, a first honeycomb, a first  
septum, a second honeycomb, a second septum, a third  
honeycomb and a solid skin. The present invention can  
be applied:

- 30 • to the monitoring of a first septum assembled with  
the two honeycombs which are adjacent to it, the  
illumination system being episcopic or diasopic,
- to the monitoring of the second septum after its  
assembly so as to constitute a subassembly  
35 including the two septums and the three honeycombs,  
the monitoring then being carried out with an  
episcopic illumination system,
- to the monitoring of the two septums after their

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assembly with the three honeycombs, the monitoring then being carried out with an episcopic illumination system, it being possible for the assembly to be carried out in a single heat cycle

5 in an autoclave, with the three honeycombs.